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Marine litter occurrence patterns along the Portuguese coast in the past decade

Mestrado em Ecologia Marinha

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Resumo

O lixo marinho captou a atenção da comunidade científica nas últimas décadas, passando a constituir um problema central na conservação do meio marinho. Associado a uma vasta diversidade de atividades humanas, que podem ocorrer tanto em zonas costeiras, como em zonas oceânicas, o lixo marinho tornou-se um problema global, de extensão e magnitude desconhecidas, que põe em risco os ecossistemas marinhos e as economias que deles dependem. A acumulação de lixo nas zonas costeiras reduz substancialmente o potencial turístico da região afetada, sendo a solução mais comumente adotada, a remoção mecânica dos detritos sólidos, economicamente insustentável a longo prazo. Desta forma, é possível observar um aumento da preocupação em relação ao lixo marinho costeiro, evidente no crescente número de estudos desenvolvidos nas praias, e também nas inúmeras iniciativas que visam mitigar este problema. O Projeto Coastwatch é um projeto europeu, desenvolvido inicialmente na Irlanda em 1988, que tem como objetivo recolher informação de base sobre a zona costeira, sendo uma das temáticas abordadas o lixo marinho. É um projeto de *citizen science*, que recorre ao auxílio de voluntários não cientistas para a recolha dos dados. Usando um questionário padrão, os voluntários do projeto Coastwatch, em inúmeros países da Europa, recolhem informação sobre a dinâmica costeira, fauna e flora, lixo marinho, entre outras componentes da costa, nas zonas costeiras dos países envolvidos no projeto. O objetivo da presente dissertação de mestrado foi identificar padrões espaciais e temporais na deposição de lixo na costa portuguesa, usando os dados recolhidos no âmbito do Projeto Coastwatch Portugal, entre os anos de 2001 e 2010. Devido à heterogeneidade dos questionários, os quais sofreram alterações ao longo dos anos, foi necessário proceder a uma criteriosa análise e transformação dos dados recolhidos, de forma a ser possível realizar comparações entre os diferentes anos. Todos os dados que tinham sido recolhidos na forma de abundâncias foram transformados em classes de abundância (0 itens; classe 1: 1-5 itens; classe 2: 6-50 itens; classe 3: 51-100 itens; classe 4: > 100 itens), de forma a estarem de acordo com o questionário mais recente. Devido à heterogeneidade das áreas amostradas, todos os dados foram organizados por regiões, ordenadas de 1 a 7 segundo as NUT III em vigor (1 - Minho-Lima, Cávado e Grande Porto; 2 – Baixo Vouga, Baixo Mondego e Pinhal litoral; 3 – Oeste; 4 – Grande Lisboa; 5 – Península de Setúbal; 6 – Alentejo Litoral; 7 – Algarve). As regiões 1 e 2 são compostas por mais do que uma NUT III por forma a

agregar um número de amostras idêntico ao das restantes áreas. Cada região foi caracterizada tendo sido selecionadas 3 variáveis: população residente, número de estuários, número de portos e número de distritos industriais. Os dados foram analisados por ano e por região, de forma a determinar padrões e tendências, tanto temporais como espaciais. As diferenças entre as regiões e os diferentes anos foram exploradas através de uma ANOVA multivariada permutacional (PERMANOVA) e de um teste Simper. Na análise da distribuição de lixo nas diferentes regiões, ao longo do tempo, e da sua relação com as variáveis ambientais, foi realizado uma Análise de Coordenadas Principais (PCO). As categorias de lixo marinho mais abundantes na costa portuguesa foram o plástico, os aparelhos de pesca, os sacos de plástico, o vidro e o papel e cartão. As regiões Norte (1, 2 e 3) apresentaram uma maior abundância de lixo comparativamente às regiões do centro (4 e 5) e do Sul (6 e 7). O plástico apresentou uma ligeira tendência geográfica, evidenciando uma diminuição no sentido Norte-Sul. Foi também possível observar que as categorias de lixo mais abundante, com exceção dos aparelhos de pesca, apresentaram os menores valores na região 4 (Grande Lisboa). Também foi possível distinguir alguns padrões temporais, tendo-se registado um ligeiro aumento da categoria plástico ao longo dos anos, com a exceção de um ligeiro decréscimo nos anos de 2003 a 2006. É importante evidenciar também que o papel e cartão, registado apenas desde 2007, apresentou um decréscimo ao longo do tempo, tendo-se registado valores extremamente reduzidos em 2010. Os resultados da PERMANOVA mostraram que tanto as diferentes regiões amostradas como o ano em que as amostras foram recolhidas têm uma influência significativa na quantidade de lixo. Foram também evidenciadas diferenças entre as quantidades de lixo recolhidas em diferentes anos e em diferentes regiões. O ano de 2010 apresentou grandes diferenças em relação à grande maioria dos outros anos amostrados, assim com a região 7 (Algarve), que apresentou diferenças significativas entre todas as outras regiões, com a exceção da região 4 (Grande Lisboa). No entanto, os anos de 2003 e 2004 não apresentaram diferenças significativas com nenhum dos restantes anos amostrados. A PCO realizada explicou 72.5% da variância total, não evidenciando, no entanto, padrões muito definidos. A primeira componente principal apresenta-se positivamente correlacionada com a região 7 (Algarve), evidenciando deste modo uma correlação entre as quantidades de lixo neste região com o número de portos presente. Por fim, os resultados do teste Simper mostram que as diferenças evidenciadas entre a região 7 (Algarve) e as restantes regiões amostradas se deve principalmente à reduzida abundância de lixo recolhido nesta região, sendo que a categoria responsável pela principal percentagem de diferença foi o plástico, com exceção da região 5 (Península de Setúbal), onde o número de pneus encontrados, bastante mais elevado que nas restantes regiões, representou a percentagem maioritária das diferenças encontradas. As diferenças registadas no ano de 2010 são devidas, principalmente, às menores quantidades de papel e cartão recolhidas nesta região As categorias de lixo mais abundantes registadas neste estudo estão em concordância com vários outros estudos realizados em outras zonas do mundo. O plástico é, universalmente, o principal poluidor dos oceanos. Mesmo apresentando diferenças não muito marcadas, os resultados deste trabalho mostram que o plástico está a aumentar ao longo do tempo, na costa portuguesa. Existe ainda uma grande necessidade de monitorização a longo prazo, de forma a ser possível avaliar a quantidade, tipologia e distribuição de lixo em Portugal, e uma das grandes fraquezas dos dados recolhidos no âmbito do Projeto Coastwatch Portugal é a heterogeneidade no registo da informação, impedindo assim o seu uso como ferramenta de monitorização a longo prazo. Será necessário proceder a uma reformulação da metodologia, de forma a possibilitar o uso dos dados do Projeto Coastwatch para monitorizações a longo prazo. O questionário não deve sofrer novas alterações, e os dados referentes ao lixo marinho devem ser registados na forma de abundância, e não de categorias de abundância. Será também necessário implementar um protocolo de controlo de qualidade dos dados, de forma a evitar dados incorretos, que têm de ser eliminados posteriormente. Apesar das suas fraquezas, o Projeto Coastwatch é uma fantástica ferramenta de monitorização e educação ambiental, com resultados recolhidos em diversos anos, em diversos países europeus. Com os dados deste Projeto, foi possível com este estudo começar a entender a dinâmica do lixo marinho na costa portuguesa, assim com as principais categorias presentes na nossa costa. Sendo o plástico o principal componente do lixo marinho, tanto em Portugal como em outros países, é necessário focar as atenções neste componente em particular. Devido ao seu longo tempo de vida no ambiente marinho, é importante encontrar soluções e medidas mitigadores para este problema o mais rapidamente possível, tanto a nível nacional como a nível internacional.

Abstract

Marine litter has become a worldwide problem, attracting the attention of the scientific community. It poses a threat to wildlife and to the economic value of the region affected by it. Marine litter is present in virtually every place of the marine environment, from the deep sea to the coastal areas. Managing and minimizing the impacts of marine litter is an important task that needs to be properly addressed. In order to do so, long term monitoring campaigns have been developed by various groups and associations, in order to quantify and qualify marine litter. One of those programs, the Coastwatch Project, has been working for over twenty years and has collected data on marine litter found on beaches from several European countries. This study uses the data collected by the Coastwatch Project from 2001 to 2010, in Portugal, to determine temporal and spatial patterns in the distribution of marine litter in the Portuguese coastline. The data from different years was standardized in order to compare different years among each other, and the data was organized in seven regions, from North to South. The dominant types of litter recorded were plastic and fishing gears. The northern regions appear to have more litter than the central and southern regions, with plastic clearly decreasing towards the South. The statistical analysis showed that both the regions and the different years influenced the amount of marine litter found, with 2010 being the year with the largest differences. Region seven was the region with the bigger differences from the others. It was possible to understand some of the trends of marine litter in the Portuguese coast, as well as the main types of litter found, and to identify some of the weaknesses present in the Coastwatch Project, in order to help improving it for the future.

Key-words: Marine litter, long term assessment, Coastwatch Project.

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Chapter 1: General Introduction

Today, there is no place on the world's oceans that has not been affected by human influence (Halpern *et al.*, 2008). The increase in population density living in coastal areas and their economic activities, both on land and at sea, have strongly contributed to generate negative impacts in the marine environment¸ in such a way that the work and money required for management and conservation of these areas can be overwhelming (Crain *et al.*, 2009; Halpern *et al.*, 2007).

There are multiple threats to the marine environment. Loss of natural habitats was, for many years, the most stressing and widespread threat to the coastal ecosystems mostly because these systems have been drained, dredged and transformed into artificial soil or open waters (Crain *et al.*, 2009). Following habitat loss, the fishing industry was responsible for most of today's threats to marine life. Apart from the obvious overexploitation of natural resources, the fishing industry has generated other problems, such as bycatch and the generation of debris from fishing nets, lost or discarded at sea, became some of the main threats to the marine environment (Dayton *et al.*, 1995). Impacts resulting from fishing also include the destruction of benthic habitats by bottom trawlers, which can take a very long time to recover from damage (Halpern *et al.*, 2007).

Industrialization led to new threats, like pollution of water bodies by toxins, fertilizers and many other contaminants, that eventually reach the ocean (Crain *et al.*, 2009). More recently, large scale, planet-wide threats like climate change have been largely documented (Halpern *et al.*, 2007). Consequences of climate change include, but are not restricted to, an increase in temperature, a rise in sea level, ocean acidification and an increase in UV exposure (Crain *et al.*, 2009). Such a variety of impacts needs to be addressed according to its geographical scale. Global scale threats like climate change need to be addressed in the regional and global level, but more localised impacts like the increase in coastal urban development, which causes an increased pressure in the coastline, needs to be addressed at the local and regional levels (Halpern *et al.*, 2007). The impacts caused by the pollution of solid man-made debris is also considered an international threat (Frost and Cullen, 1997), and as such, must be addressed not only at a regional level, but also at an international level. Anthropogenic debris can even be found at great depths, interfering mainly with sessile communities (Angiolillo *et al.*, 2015), and as such it can have a negative effect in every habitat of the marine ecosystem.

According to Galgani et al. (2010), anthropogenic solid waste, commonly referred to as marine litter, can be considered “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment”. The history of marine litter is strongly related to that of plastic, beginning in the last five decades. Since identified in the 1960’s, marine litter did not have the attention of the scientific community, but through the decades of 1970 and 1980 it started being approached as a complex scientific problem, with data being collected about its distribution, abundance and impacts, with new political approaches being made, mainly in the 1990´s and onwards. (Ryan, 2015).

Two papers published in 1972 (Carpenter and Smith, 1972; Carpenter *et al.*, 1972) contributed greatly to stimulating scientific interest in marine debris and its impacts (Ryan, 2015). Carpenter & Smith (1972) collected a large amount of plastic residues while sampling in the Sargasso Sea, in the North Atlantic, with surface nets. 3500 particles of plastic were recorded per square kilometre, being the first time this type of residue was recorded in the scientific literature. It was also noted that the only impacts recorded were the formation of sessile colonies on these particles. Carpenter et al (1972) found plastic spherules while doing surface trawls in Niantic Bay, Connecticut, USA. They were clearly different from the ones found in the Sargasso Sea, and were registered as being ingested by different fish species present in the area. Both papers drew the attention of the scientific community to ocean pollution by anthropogenic debris, and identified three possible impacts this type of litter could have on the marine environment: intestinal blockage due to ingestion, a source of toxic compounds and the transport of invasive epibionts (Ryan, 2015).

In the 1970’s, the attention towards marine litter stranded on beaches increased (Ryan, 2015). Scott (1972) pointed out that, contrary to popular belief, litter stranded on the coast did not necessarily come from beach users, or that discarded litter remained in the same place until being collected. Sampling two isolated beaches in Scotland, with very difficult access, it was verified that most, if not all, debris had been brought in by the sea, despite having an obvious land-based source. The types of litter typically associated with beach goers were also absent (i.e. soft drink containers) (Scott, 1972; Ryan, 2015). Cundell (1973) investigated for the first time the rate of accumulation of litter in a beach, collecting litter and returning the next month, estimated an accumulation rate of 0.96 g m^{-2}, on a beach on Rhode Island, USA. Wong et al. (1974) presented the first quantitative analysis of plastic residues in the Pacific ocean, and Gregory (1977) reported the accumulation of plastic pellets in most of the beaches in New Zealand. In the 1970's, the first records of litter in the sea bottom were also published (Ryan, 2015).

In the early 1980's, Merrell (1984) made the first detailed study about the accumulation of litter on beaches. This study compared surveys made in Amchitka Island, Alaska, with others conducted in previous years, discussing the relationship between litter and its main source, in this case commercial fishing (Merrell, 1984; Ryan, 2015). Building upon the records from Carpenter & Smith (1972), Winston (1982) suggested that plastic and other floating residues could serve as vessels to sessile organisms.

The 1980's were also the time when the first international meetings of the scientific community on marine litter took place. With the increased awareness and concern of the scientific community, the first Workshop on the Fate and Impact of Marine Debris took place, in 1984. This workshop focused on the need to increase awareness about marine litter and its threats, recommending three mitigation measures: the regulation of the disposal of high risk plastic items, the promotion of fishing net recycling and the investigation on the use of biodegradable materials in fishing gear (Ryan, 2015). Even before holding a second conference, the Sixth International Ocean Disposal Symposium, on April, 1986, focused greatly on ship-based litter sources and its impacts, touching even the topics of bycatch by fishing gear and land-based marine litter sources (Ryan, 2015).

The Second International Conference on Marine Debris finally took place in April, 1989, focusing more in finding a solution to the marine litter problem. These first two conferences gave an important contribution to the awareness and notoriety of the marine litter problem, with three conferences that followed (Ryan, 2015). In the 1990's, there was a decrease in the scientific activity related to marine litter, but the confirmation that microplastics are marine pollutant and the media attention to the formation of mid-ocean garbage patches stimulated the scientific interest and increased the awareness of the public towards the problem of marine litter (Ryan, 2015).

At the international level, there have been some initiatives to address firstly the pollution problem in general, and secondly the marine litter pollution in particular. The first international convention for the protection of the marine environment from human activities was the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (also known as the London Convention), signed in 1972, and enforced since 1975. The objective of this convention was to promote the control of all sources of marine pollution and to promote the prevention of pollution by dumping of wastes and other materials in the sea (www.imo.org – accessed 09/09/2015, 14:57).

Due to serious incidents involving the spillage of hydrocarbon fuels due to boat accidents, the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted in 1973, with a new protocol being signed in 1978. MARPOL 73/78, as it is known, is the main international convention that covers marine pollution by ships. It includes regulations to prevent and minimize the pollution caused by ships and includes six annexes, one of which (Annex V – Prevention of Pollution by Garbage from Ships) focus directly on marine litter. This annex covers different types of litter and specifies the distances to the coast and the methods used to dispose of residues. It also prohibits any disposal of plastic waste (www.imo.org – accessed 09/09/2015, 14:25).

The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention or HELCOM) was signed in 1974. It covers all areas of the Baltic Sea and includes measures to prevent and reduce land-based pollution (www.helcom.fi – accessed 09/09/2015, 11:40). This convention prepared the Recommendation for the Harmonization of Methods of Sampling and Reporting the Amount and Type of Marine Litter, for all the coast of the Baltic Sea, and a survey for reporting marine litter, in order to standardize data from future initiatives (Galgani et al. 2010).

Similar to what happened for the Baltic Sea, Mediterranean countries adopted the Convention for the Protection of the Mediterranean Sea against Pollution (also known as Barcelona Convention), in 1976. Actions addressing marine and coastal litter, with preparation of a relevant assessment, began in 1999 with a general questionnaire about Litter Management in Coastal Zones of the Mediterranean being sent to all countries. In 2008, with the results of this questionnaire, an Assessment of Marine Litter in the Mediterranean was prepared, with results from beach cleanings and floating litter monitoring (Galgani et al. 2010).

The most important step towards marine litter assessment came from the Convention for the Protection of the Marine Environment of the North-East Atlantic. Resulting from the joining of the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircrafts (Oslo Convention, 1974) and the Convention for the Prevention of Marine Pollution from Land-Based Sources (Paris Convention, 1978), in 1992, this new Convention for the Protection of the Marine Environment of the North-East Atlantic, commonly known as OSPAR convention, is the mechanism by which fifteen governments of Europe’s West coast, together with the European Community, cooperate to protect the marine environment in the North-East Atlantic ocean (Galgani et al. 2010; www.ospar.org - accessed 09/09/2015, 11:35). The 2007 OSPAR Pilot Project on

Monitoring Marine Beach Litter was the first European project to develop a standard methodology for monitoring the marine litter found on beaches. In 2009 it was released OSPAR's Assessment of the Marine Litter Problem in the North-East Atlantic Maritime Area and Priorities for Response, which takes old projects that identified a need for a standard methodology and resulted in a comprehensive analysis of quantities, composition and trends in marine litter in the OSPAR maritime area. Finally, in 2010, the Guidelines for Monitoring Beach Litter were published, which made the monitoring of beach litter a formal instrument of assessment (Galgani et al. 2010; OSPAR Commission 2010).

Finally, the United Nations Environment Program also developed an initiative on marine litter, and focused on the establishment and development of regional activities (www.unep.org – accessed 09/09/2015, 17:22). The UNEP Global Initiative on Marine Litter establishes a platform for managing the problem of marine litter in order to make partnerships to solve this problem. This initiative was very successful in organizing, establishing and promoting activities all around the world (UNEP, 2009).

In order to study marine litter, there is a need to assess large scale patterns, which requires collecting a large amount of data, throughout different geographic locations and during an extended period of time (Bonney *et al.*, 2009). However, there are economic and logistic factors that prevent scientists from collecting such a volume of data (Roy *et al.*, 2012). One way to obtain such an amount of information is through citizen science (Bhattacharjee, 2005; Bonney *et al.*, 2009). Citizen science is a research technique that uses members of the general public to collect scientific data (Bonney *et al.*, 2009). Citizen science may be considered a recent research method, but examples of such practices date back to the 19th century, and throughout the 20th century, citizen volunteers participated in projects in various areas, ranging from water quality, species distribution and astronomy (Bonney *et al.*, 2009; Science Communication Unit University of the West Of England Bristol, 2013). However, one of the main criticisms about citizen science is the lack of acceptance from the scientific community, due to the untrained nature of the volunteers, making the acceptance of volunteer-collected data by the scientific community the main challenge this method of research faces nowadays (Bonney *et al.*, 2009; Roy *et al.*, 2012; Science Communication Unit University of the West Of England Bristol, 2013). Despite the criticism, citizen science projects can collect valid scientific data. In order to do so, the researches in charge of the project must guarantee that: the research protocols are clear and straightforward; supplying simple and logical data forms;

and offer the maximum amount of support to the volunteers, in order for them to be able to follow the protocols and to be able to collect the data correctly (Bonney *et al.*, 2009; Hong *et al.*, 2014). Citizen science projects must also cover questions that only require a set of basic skills in order to sample the data (Bonney *et al.*, 2009). This makes citizen science a perfect methodology for the research on marine litter, especially using beach surveys, since it requires only the ability to collect and identify litter items. An example of a project that uses citizen science in order to collect data on marine litter is the Coastwatch Project.

Coastwatch Europe is an international net of environmental groups, universities and other educational units that, joined by local groups all over Europe, work together for the protection and sustainable use of the coastal resources. This initiative works towards an informed public participation in the management and planning of the coastal areas (www.coastwatch.org – accessed 10/09/2015, 10:56). Among many other coastal monitoring campaigns, this project includes the monitoring of marine litter. Coastwatch Europe was founded in 1988 by the Dublin Bay Environmental Group, with core funding from the European Community through DGXI (Pond and Rees, 2000).

The present study aims to determine patterns of marine litter in the Portuguese coast, as well as possible temporal and spatial trends, based on a ten year dataset collected in the scope of the Coastwatch Program in Portugal. Besides this introductory chapter, this thesis comprises a research paper and some final remarks, which point out aspects that should be taken into consideration in monitoring programmes and on the Coastwatch initiative.

Chapter 2: Marine litter occurrence patterns in the Portuguese coast in the past decade

2.1. Introduction

In the past two decades, marine litter has received increased attention from the scientific community, being currently recognised as a global problem for all oceans (Abu-Hilal and Al-Najjar, 2004; Dixon and Dixon, 1981; Frost and Cullen, 1997; Ivar do Sul and Costa, 2007). There was a time when oceanic pollution by marine litter was overshadowed by the aesthetic impacts and other pollution issues like heavy metals and hydrocarbons (Heyerdahl, 1971; Laist, 1987), but more recently the concern about the amount of man-made materials in the oceans has increased, and has been acknowledged as a major form of marine pollution (Laist, 1987; Ribic *et al.*, 1992).

Debris found in the marine environment can originate from two different sources: land-based or marine-based sources. Anthropogenic input is, however, the main source (Frost and Cullen, 1997; Rees and Pond, 1995). Globally, it is estimated that land-based sources contribute with 80% of the litter in the marine environment, with only 20% coming from marine-based sources (Trouwborst, 2011). However, this can vary with geographical location and human activities, as observed in the North Sea, where the main type of litter found comes from fishery activities (Trouwborst, 2011). Associated with a plethora of human activities that can occur in the coast or far offshore, the marine debris can be transported by oceanic currents towards the coast (Bravo *et al.*, 2009), where it becomes an economic and aesthetic that is a matter of concern for various stakeholders.

Beach pollution by solid man-made wastes is a worldwide phenomenon and it poses a threat to wildlife, as well to the economic value of the region as a tourist attraction, and it is a clear sign of human impacts in the coastal environment (Araújo and Costa, 2007; Benton, 1995; Bravo *et al.*, 2009; Taffs and Cullen, 2005).One of the main problems with marine litter is that it can be toxic, both for human and for marine wildlife, especially if the debris in question are from medical, military or industrial origin (Frost and Cullen, 1997). There are two types of direct interaction between marine debris and marine organisms: entanglement and ingestion. Entanglement occurs when loops and openings in different types of debris entangle or entrap animals (Laist, 1997). One of the major consequences of entanglement is ghost fishing, which can be described as the death of commercial and non-commercial species by passive fishing gear lost or discarded at sea

(Brown and Macfadyen, 2007; Winston *et al.*, 1997). The ingestion of marine debris can cause external and internal wounds, blockage of the digestive tract (leading to starvation), reduction of quality of life and reproductive capabilities, decreasing the ability to evade predators and to find food, as well as many other consequences (Gregory, 2009). Besides the problems caused to marine wildlife, debris on beaches are also difficult and costly to remove, causing negative impacts to the local economy (Frost and Cullen, 1997). However, the main concern of the public and the media is the aesthetic degradation, and the possible impacts in tourism, resulting from the accumulation of marine debris on beaches (Gregory, 2009).

Despite the fact that beach litter is a recognized problem, the general public remains indifferent, showing some ignorance about the magnitude of this problem (Storrier and McGlashan, 2006). Nevertheless, there has been an increasing effort towards dealing with the problem of marine litter, mainly in beaches, as evidenced by studies using traditional beach surveys (Abu-Hilal and Al-Najjar, 2004; Araújo *et al.*, 2006; Oigman-Pszczol and Creed, 2007). Other methods used include the study of litter generated by beach users (Ariza *et al.*, 2008), assessment of floating marine debris, either by oceanic cruises (Thiel *et al.*, 2003) or by satellite data (Martinez *et al.*, 2009), and of deep-sea debris, using remote-operated vehicles (ROV) (Angiolillo *et al.*, 2015; Mordecai *et al.*, 2011). Another method that is gaining popularity in marine litter research is the use of citizen science projects, relying on the help of volunteers to gather scientific data (i.e. Kusui & Noda 2003; Bravo et al. 2009; Gago et al. 2014).

Using citizen science projects in studies that require a large geographical and temporal data scale helps to surpass the economical and logistical difficulties that these studies usually present (Bonney *et al.*, 2009; Roy *et al.*, 2012). The wide distribution of marine litter, and the fact that very little knowledge is needed for litter identification and collection, makes it a focus of citizen science projects (Galgani *et al.*, 2015; Hidalgo-Ruz and Thiel, 2015; Roy *et al.*, 2012; Science Communication Unit University of the West Of England Bristol, 2013). Also, marine litter quantification and distribution is the focus of most studies on marine litter, making it easy for volunteers to participate in these projects, since beach cleanups are one of the most popular activities among volunteers (Hidalgo-Ruz and Thiel, 2015). Nevertheless, some steps should be taken, in order to address one of the main weaknesses of this method: the possible lack of reliability in the data collected (Hidalgo-Ruz and Thiel, 2015). Researchers should guarantee a clear protocol, an easy to follow data sheet, support to the volunteers (in the form of workshops or with the participation of a researcher) and revision of the data collected, in order to obtain quality and unbiased scientific data (Bonney *et al.*, 2009; Hidalgo-Ruz and Thiel, 2015; Roy *et al.*, 2012). An example of a large scale citizen science initiative is the Coastwatch Project (Earll *et al.*, 2000).

Project Coastwatch is an European project that has as main objective the monitoring of the coastline with the help of volunteers (Pond and Rees, 2000). It started in Ireland in 1988, founded by the Dublin Bay Environmental Group, and has since been developed in other European countries (Pond and Rees, 2000; Simões *et al.*, 2003). The project started in Portugal in 1989, and has since been coordinated by GEOTA, a national Environmental Non-Governmental Organization. Being a citizen science initiative, the project employs the use of teams of volunteers to gather the data. The teams are composed mainly of students, from different levels of education. Each team is assigned an area of coast, and uses a standard questionnaire to record all the data. All the questionnaires are identical across countries and each coastal unit is assigned a questionnaire, identified with a serial number (Pond and Rees, 2000).

The objective of this study is to determine patterns and trends of marine litter occurrence in the Portuguese coast in the past decade, using data collected by the Coastwatch Project.

2.2. Materials and Methods

Data relative to marine litter was obtained from the Coastwatch Project conducted in Portugal, from 2001 to 2010. This data was collected by the volunteers that participated in the Coastwatch project, and was recorded in the field data forms. In order to fill these data forms the volunteer teams are instructed to walk along the coastline, first by the tide mark, and then through the splash zone. Volunteers are encouraged to conduct this visit as close to low tide time as possible (Pond and Rees, 2000). The maximum possible help is offered to each volunteer to guarantee that the questionnaire is as complete and as accurate as possible (Pond and Rees, 2000).

The questionnaire to be filled in by volunteers, covers an array of topics related to the coastline. To record the data about marine litter, the questionnaire divides the litter into categories. The categories used to classify litter items, as of the latest Coastwatch questionnaire, are the following: glass; metal; potentially dangerous products; plastic; cardboard packages; plastic bags; wood boxes; fishing gear; medical and synthetic materials; textiles; paper and cardboard; organic wood; other wood; tires; batteries; car batteries; and others. However, in the past, different categories have been used. Between 2001 and 2006, only the categories glass, cans, plastic, can holders, cardboard packages, tyres, and plastic bags were recorded.

In order to assign a specific area to a group of volunteers, the Portuguese coast map is divided in 5 km areas in each region. Then each 5 km area is further divided into zones of 500 m. Each volunteer team, usually composed by students, was assigned to a zone, according to their residential area. The teams use the standardized questionnaire to register the amount of litter in the zone they were assigned to. The number of sectors sampled in each region between 2001 and 2010 varied greatly. So, in order have a similar number of sampled areas in each region, the regions Minho-Lima, Cávado and Grande Porto were grouped into region 1, and the regions Baixo Vouga, Baixo Mondego and Pinhal Litoral were grouped into region 2. The remaining regions were numbered as well: region 3 (Oeste), region 4 (Grande Lisboa), region 5 (Península de Setúbal), region 6 (Alentejo Litoral), and region 7 (Algarve). After this alterations, the number of sectors sampled in each region varied from 488 to 1903 (Table 1).

Table 1 – Number of 500 m units of coast samples, per region, in each year.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
1 - Minho-Lima, Cávado and Grande Porto	99	173	131	41	147	24	15	130	11	21	792
2 - Baixo Vouga, Baixo Mondego and Pinhal Litoral	149	629	335	291	403	139	269	374	168	159	2916
3 - Oeste	172	255	186	172	199	17	163	223	54	85	1526
4 - Grande Lisboa	115	120	151	118	254	0	40	117	30	58	1003
5 - Península de Setúbal	94	126	180	369	281	87	129	248	36	83	1633
6 - Alentejo Litoral	219	171	230	157	188	10	31	77	18	10	1111
7 - Algarve	162	326	208	171	431	211	180	232	259	211	2391
Total	1010	1800	1421	1319	1903	488	827	1401	576	627	11372

In order to make a comparative analysis between different years and regions, some alterations to the data were needed. Data incorrectly recorded were excluded. This included samples recorded without date. The input sheets were standardized: data from 2001 up to 2006 (registered as abundance) were transformed in accordance with the categories used from 2007 onwards. These categories were: between 1 and 5 items (class 1), 6 and 50 items (class 2), 51 and 100 items (class 3), and more than 100 items (class 4). The absence of litter was classified as zero. In order to have an extended and integrated view of all the categories and years, the mean value of some categories was used to fill the voids left behind by the questionnaires, in some of the years.

The data were analysed by year and by region, to evaluate temporal and spatial trends. The data were transformed using a square root transformation, so that the results were not influenced by the dominant categories or by the rare categories. A permutational multivariate ANOVA (PERMANOVA) was used to analyse if there were differences between regions and years. This analysis was based on a resemblance matrix built using Bray-Curtis similarity (Castro *et al.*, 2013; Mckinley *et al.*, 2011). In case a significant effect was found, pairwise tests among all pairs of the given factors were carried out. A Principal Coordinates Analysis (PCO) was made in order to visualize the relationships between the distribution of litter across the different regions and throughout time, and different environmental variables. The environmental variables used in this analysis were: the number of estuaries, the number of ports, total population (Instituto Nacional de Estatística, 2006) and the number of industrial districts (classified according to the percentage of the population employed in the industrial sector) (Ferreira, 2011) (Table 2). In order to evaluate which litter categories influenced more the differences recorded, a Simper test was used. The influence of each litter category in the difference between years and regions was calculated until a cumulative percentage of approximately 50%. All analyses were performed using the software PRIMER v6.0 (Clarke and Warwick, 2001) with PERMANOVA add-on (Anderson *et al.,* 2008).

Table 2 – Environmental and social variables in each region

	Estuaries	Ports	Population	Industrial districts
1 - Minho-Lima, Cávado and Grande Porto	8	4	1936405	16
2 - Baixo Vouga, Baixo Mondego and Pinhal Litoral	6	1	996084	7
3 - Oeste	7	3	356296	1
4 - Grande Lisboa	3	4	2012925	0
5 - Península de Setúbal	2	3	766172	1
6 - Alentejo Litoral	6	3	97179	1
7 - Algarve	13	8	416847	0

2.3. Results

The five major types of litter recorded were plastics, fishing gears, plastic bags, glass, and paper and cardboard (Table 3).

Table 3 – Mean category and standard deviation (Std.dev.) of all litter classes

	Mean	Std. dev.
Plastic	1.46	1.22
Fishing gear	1.04	0.59
Plastic bags	1.02	1.05
Glass	0.98	0.97
Paper and cardboard	0.86	0.58
Metal	0.82	0.88
Cardboard packages	0.76	0.89
"Green" waste	0.75	0.38
Other wood	0.70	0.32
Textiles	0.62	0.44
Synthetic packages	0.57	0.37
Cans	0.54	0.35
Other glass	0.53	0.33
Medical waste	0.47	0.41
Dangerous waste	0.46	0.38
Other waste	0.38	0.22
Wood boxes	0.32	0.24
Tires	0.26	0.54
Supports	0.17	0.40
Batteries	0.07	0.15
Car batteries	0.02	0.07

In general, the northern region (1, 2 and 3) had more litter than the center (4 and 5) and southern (6 and 7) regions, with region 7 having the lowest values of all the regions (Figure 1). Plastic litter shows a slight geographical trend, being more abundant in the northern regions, decreasing slightly towards the south. With the exception of fishing gears, every litter category seems do decrease slightly in region 4 (Figure 1). The temporal patterns also shows some trends. With the exception of a small decrease in the period of 2003 to 2006, it shows that plastic debris increased during the study period. Paper and cardboard, recorded only from 2007 onwards, showed a drastic decrease, with 2010 having the lowest values in this category (Figure 2).

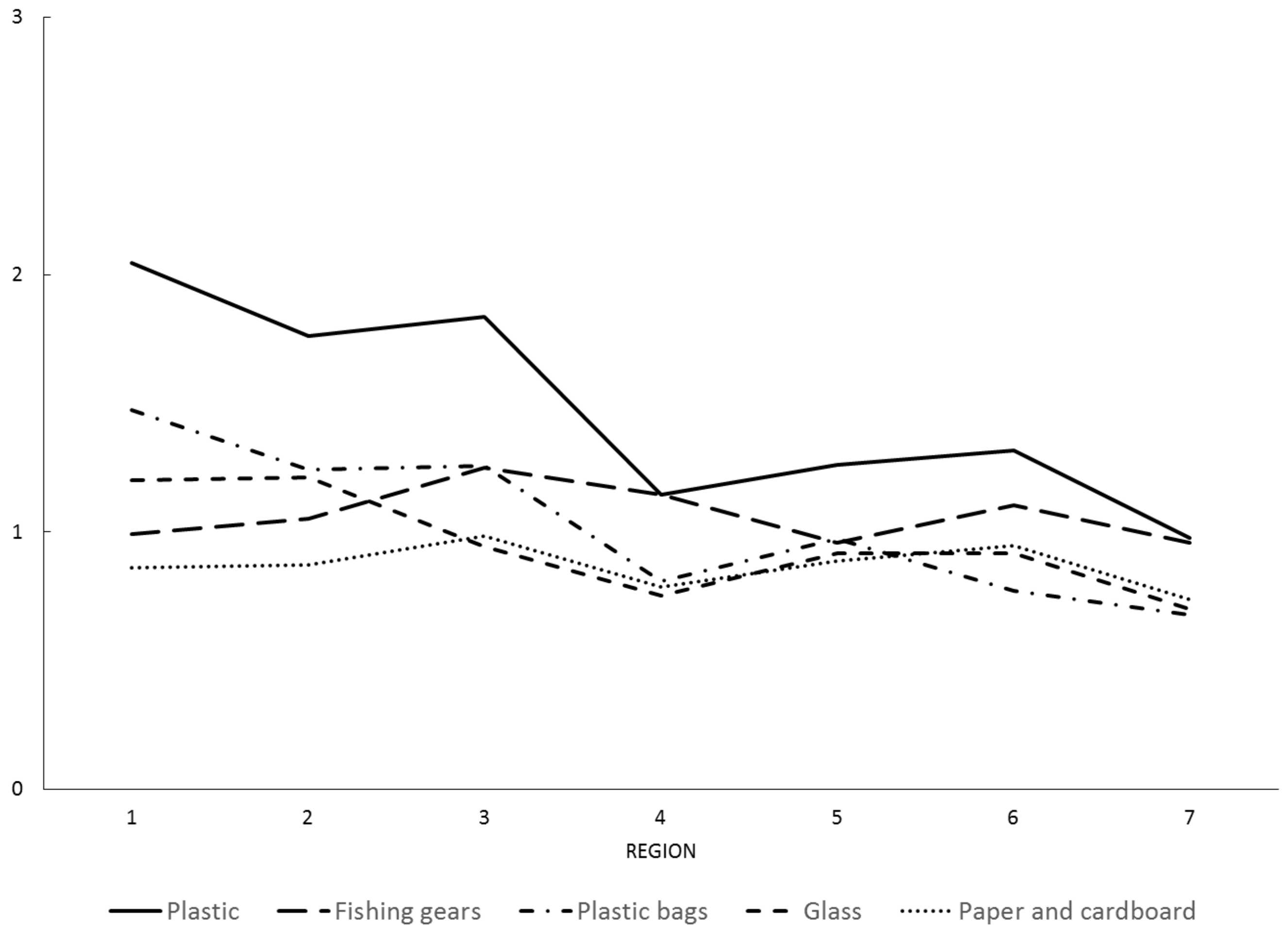

Figure 1 – Average litter category for the major five types of litter, in each region. Class1: 1-5 items; Class 2: 6-50 items; Class 3: 51-100 items; Class 4: > 100 items.

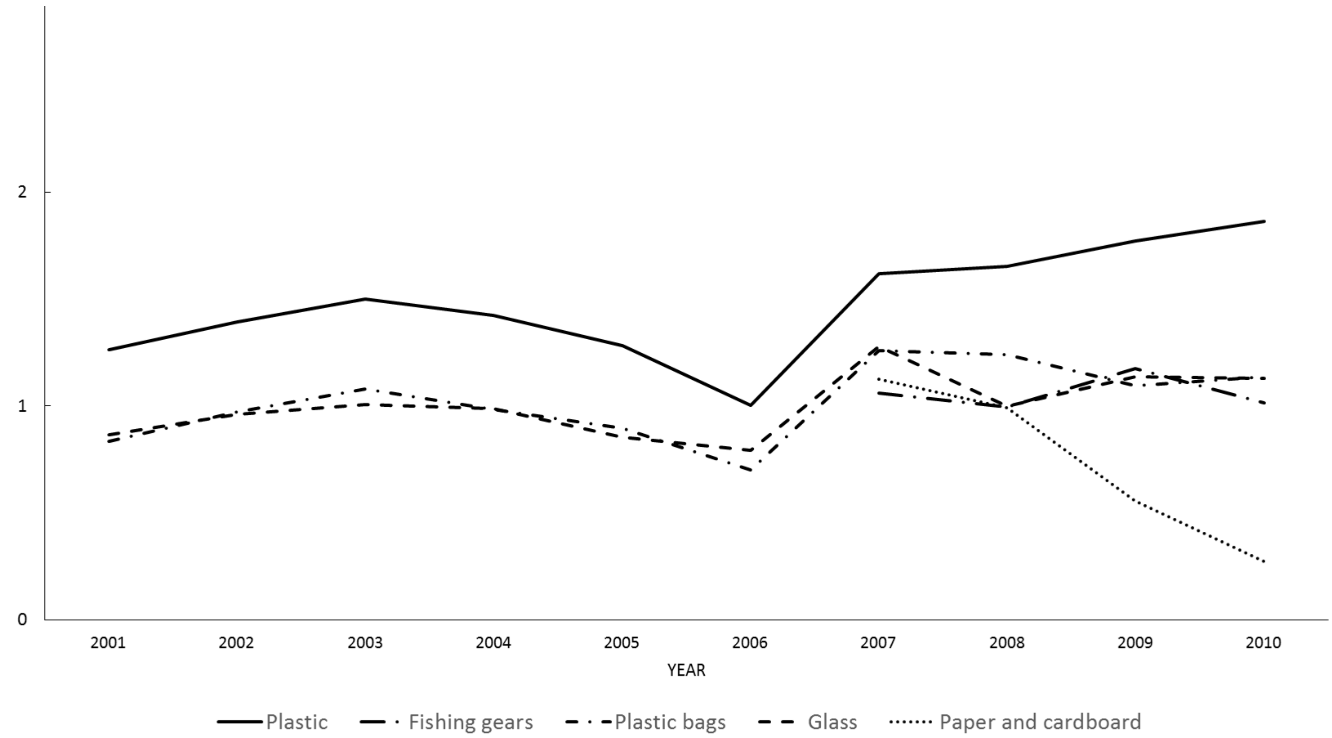

Figure 2 – Average litter category for the major five types of litter, in each year. Class1: 1-5 items; Class 2: 6-50 items; Class 3: 51-100 items; Class 4: > 100 items.

The PERMANOVA results show that the amount of litter found is influenced by the region of the country (Pseudo-F = 3.7518, $p = 0.001$) and the years (Pseudo-F = 2.9165, $p = 0.001$)(Table 4).

Table 4 – Results of the PERMANOVA analysis conducted to compare the amount of litter between the years (2001-2010) and the regions (1-7)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Re	6	767.15	127.86	3.7518	0.001	998	0.001
Ye	9	894.52	99.391	2.9165	0.001	998	0.001
Res	53	1806.2	34.079				
Total	68	3467.6					

There were significant differences, both between years (Table 5) and between regions (Table 6).

Table 5 – Results of the Pairwise PERMANOVA comparisons between years (*p-values*). Significant differences (*p <0.05*) in bold.

Years	2001	2002	2003	2004	2005	2006	2007	2008	2009
2001									
2002	0.466								
2003	0.120	0.149							
2004	0.105	0.071	0.338						
2005	0.877	0.816	0.130	0.113					
2006	0.494	0.621	0.727	0.783	0.630				
2007	**0.025**	**0.028**	0.098	0.135	**0.038**	0.057			
2008	0.063	0.069	0.140	0.188	0.076	**0.049**	0.305		
2009	**0.048**	0.060	0.084	0.149	0.052	**0.006**	**0.049**	**0.024**	
2010	**0.016**	**0.021**	0.069	0.102	**0.040**	**0.021**	**0.015**	**0.016**	0.233

Table 6 – Results of the Pairwise PERMANOVA comparisons between regions (*p-values*). Significant differences (*p <0.05*) in bold.

Region	1	2	3	4	5	6
1						
2	0.271					
3	0.380	0.168				
4	**0.001**	**0.001**	**0.015**			
5	**0.004**	0.096	**0.009**	0.066		
6	0.702	0.998	0.992	**0.043**	0.374	
7	**0.001**	**0.002**	**0.004**	0.961	**0.002**	**0.003**

Significant differences include: a large difference between the year of 2010 and the majority of other years ($p < 0.05$), except 2003 ($p = 0.069$), 2004 ($p = 0.102$) and 2009 ($p = 0.233$); a lack of differences in 2003 and 2004 (all pairwise tests: $p > 0.05$); region 7 (Algarve) having significant differences with all other regions ($p < 0.05$), except region 4 (Grande Lisboa) ($p = 0.961$); and region 6 (Alentejo Litoral) having differences only with region 4 ($p = 0.043$) and 7 ($p = 0.003$).

The PCO analysis does not show a clear separation between regions. PCO axis 1 explained 51.2% of total variation inherent in the resemble matrix, and slightly separated region 4 and 7 from the bulk of the other regions. PCO axis 2 explained 22.3% of total variation. This analysis explains 72.5% of total variation. It is possible to observe that the industrial districts are negatively correlated with PCO1, and ports are positively correlated with PCO1, showing a relation between the number of ports and the amount of litter in region 7.

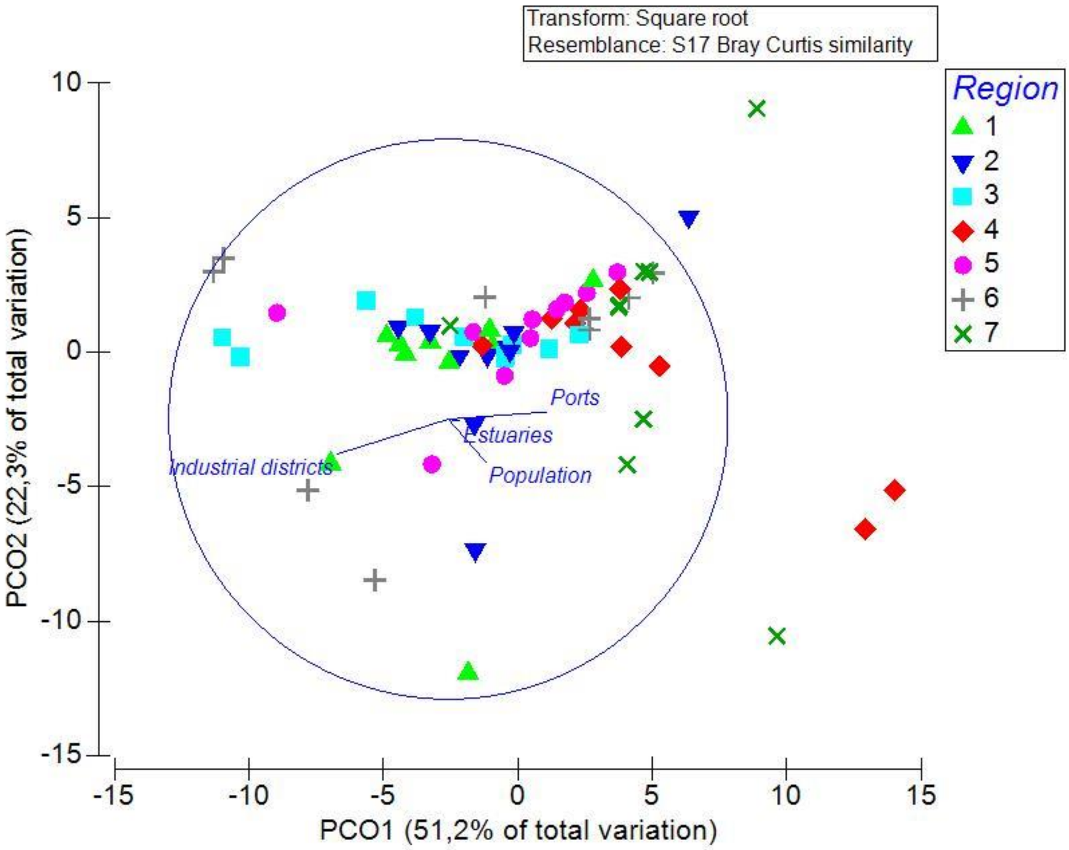

Figure 3 – PCO analysis illustrating distribution of litter in each region, and its relation with the environmental variables

The results of the Simper test showed that the year of 2010 has the greatest dissimilarities when compared with all the other years, especially with 2001 (Average dissimilarity = 18.89%) and 2007 (Average dissimilarity = 13.07%) (Table 7). These differences are mainly due to the lowest values of litter registered in 2010. These differences are mainly significant in the category paper and cardboard, especially low in this year. The only exception is with the year of 2006, when the low value of the plastic litter category exceeded the percentage of difference caused by paper and cardboard. In the case of the regions, region 7 (Algarve) is the region with the greatest dissimilarities, mainly with region 1 (Average dissimilarity = 10.32%), although region 6 (Alentejo Litoral) also showed great differences with region 1 (Average dissimilarity = 10.09%) and with region 4 (10.49%) (Table 8). Differences between region 7 and the other regions where mainly due to the lower mean categories of litter found in this region. The differences found are especially notable in the plastic category. With the exception of region 5, plastic is responsible for the largest percentage of difference between region 7 and the other regions. In region 5, the main cause of the differences found is the mean of the tires category, being more abundant in region 5 (Table 8).

Table 7 – Simper test – Average dissimilarities between years

Years	2001	2002	2003	2004	2005	2006	2007	2008	2009
2001									
2002	2.68								
2003	2.62	2.12							
2004	3.35	2.07	1.77						
2005	2.69	1.92	2.04	2.23					
2006	5.49	4.63	4.01	4.00	4.34				
2007	8.99	7.37	7.54	7.87	7.89	9.00			
2008	9.16	7.57	7.60	7.79	7.77	8.73	5.48		
2009	12.82	11.49	11.07	11.43	11.30	10.87	12.91	11.64	
2010	18.89	12.44	12.37	12.63	12.38	12.90	13.07	11.96	10.01

Table 8 – Simper test – Average dissimilarities between regions

Region	1	2	3	4	5	6
1						
2	6.38					
3	7.32	5.26				
4	9.03	7.48	9.76			
5	7.02	5.44	5.09	7.22		
6	10.04	6.98	5.91	10.49	7.16	
7	10.32	6.97	9.37	6.34	7.30	8.59

2.4. Discussion

The five dominant types of litter in the Portuguese coast were plastic (mean category 1.46), fishing gears (mean category 1.04), plastic bags (mean category 1.02), glass (mean category 0.98), and paper and cardboard (mean category 0.86), with plastic being the clear dominant (Table 3). This is a trend verified worldwide, as many studies show that plastic is generally the dominant type of litter found in beaches. Gago et al. (2014) found a majority of plastic in all the 79 surveys in the North coast of Spain, with fisheries being the main source. Abu-Hilal & Al-Najjar (2004) concluded that almost 50 % of the litter collected in the Jordan coast was composed of plastic. In Japan, Kusui & Noda (2003) found that 72.9% of litter sampled was plastic debris. Cunningham & Wilson (2003) obtained 89.8% of plastic in the samples collected in Australia's East coast, while Moore et al. (2001) found 99% of plastic in the 43 sites sampled in California, USA. Benton (1995) found that the same amounts of litter found in industrialized Europe could be found in the remote areas of the South Pacific, where plastic litter was still the clear dominant.

The clear abundance and dominance of plastic debris can be explained by a multitude of factors. With an increase in production in the last half-century, plastic is a very desirable and widespread material, because of its light weight, high durability and low production cost, which also makes it very likely to be discarded and to persist for long periods of time in the marine environment (Derraik, 2002; Laist, 1987). Some types of plastic residues are known to last for decades in the marine environment (Depledge *et al.*, 2013). Also, the annual production of plastic increased from 1.5 million tons in the 1950s to approximately 280 million tons in 2011 (Depledge *et al.*, 2013), making plastic the most abundant type of litter in the marine environment.

Though not very obvious, the results of this work show that there is a slight increasing trend in marine litter in the Portuguese coast. Other long-term monitoring studies have shown that there is no consensus about a clear trend in marine litter. Edyvane (2004) showed that, if collected, marine litter on beaches reaches a base-point, and Ribic (2010) showed that trends have a geographical variability.

One of the major problems with the building and usage of long-term data series is to maintain its continuity, quality and precision, so that the data produced is correct and homogeneous. The major problem is that beach surveys are carried out without a standardized methodology, which makes methodologies like that of the Coastwatch

Project so valuable (Gago *et al.,* 2014). The volunteer-oriented surveys used in this project have the potential to cover a large geographical area, without the need of extensive financial support, and with a minimum of equipment requirements. Also, in most cases, the types of litter found on beaches are common household and domestic items, easy to identify for most of the volunteer team members (Bravo *et al.*, 2009; Rees and Pond, 1995). However, one of the main criticisms to this type of survey is that the data collected by volunteers are not reliable or comparable with other works (Bonney *et al.*, 2009). A study conducted in North America compared the data collected by volunteers with the data collected by a team of scientists, and found that the amount of litter sampled was substantially lower in the data collected by volunteers, mainly due to the fact that the main focus of the volunteers was to clean the beach, and not to collect data (Moore *et al.,* 2001). This can be the case with some of the results presented in this study. For example, the low values of paper and cardboard in 2010 may be due to underestimations caused by lack of experience of the volunteers. Volunteers may also be biased in the collection of litter, favouring more conspicuous items.

Besides the more common weaknesses of citizen science projects, the Coastwatch Program has some other flaws. One of the major weaknesses of the program is the heterogeneity of the questionnaire over the years. This makes the comparison of data between different years very difficult. First of all, the categories vary greatly between the years. The most obvious change that occurred over the time period analyzed was the shift from recording data as abundance to recording them as abundance classes, which was used in the present questionnaire. Besides, the number of classes of abundance recorded has also increased over the years. These changes undermine one of the greatest strengths of the program, which was the large time period featured in the data, making comparative analysis difficult. Another problem was encountered when analyzing the data. Because data are collected by untrained volunteers, the data input in the spreadsheets are bound to have inaccuracies and mistakes, despite the help provided to the volunteers of the Coastwatch program. Some data had to be removed from the analysis conducted in the present study because it contained unfinished data inputs, or incorrect data.

In order to improve the Coastwatch program and bypass some of its weaknesses have to be carefully addressed to be able to take full advantage of its strengths. Having a structure already running during two decades, and a strong base of volunteers it is already half-way through to a successful assessment program. However, the problem of temporal heterogeneity deserves a special attention. Keeping the current questionnaire would solve that problem, simply because it would be possible to start a long-time analysis since 2007. However, the current questionnaire poses another problem, which is the type of data collected. The use of the litter categories is not the ideal situation to analyze the data from marine litter abundance, since it becomes of little use to provide information on the real abundance of litter on beaches and the differences between different categories. Measures of quality control should also be implemented. Appropriate control of data collected by the volunteers by an experienced researcher is an essential measure to guarantee its quality (Science Communication Unit University of the West Of England Bristol, 2013). This should be implemented in the Coastwatch Program, with researchers reviewing all the data sheets submitted. If all the appropriate measures are taken into account, it would make the Coastwatch Project much more useful, and would enable the use of its data in management actions aimed at mitigating the problem of marine debris. So, an ideal program would have a standard questionnaire, comparable throughout the time and a standard methodology using abundance of litter, instead of categories. This would require little effort in terms of questionnaire change, and is easily applied on the field, since volunteers still have to count the litter present to classify it in the categories.

Despite the weaknesses discussed above, the Coastwatch program is a good marine litter assessment program, with results in various countries in Europe, and many volunteers involved since it started, as well as an excellent tool for environmental education. Using the data collected in the scope of this project, it was possible to observe the temporal and spatial distribution of litter along the Portuguese coastline, as well as dominant types of litter

There is a great demand for more research (especially long-term monitoring) in order to assess the actual threat that marine litter (mainly plastic litter) causes in the marine environment (Derraik, 2002). This new research would help investigators offer more data to authorities in order to help solving the problem, as well as to strengthen the management of the marine environment and the environmental education campaigns (Derraik, 2002). By conducting the present study, it was possible to show some of the trends of marine litter as well as the main types of litter present in the Portuguese coastline during the past decade. Plastic litter requires more attention, due to its long life span in the marine environment (Derraik, 2002). Future studies should focus on a new and improved methodology for the Coastwatch Project, assessing its efficiency when implemented, and on the environmental impacts of marine litter in the Portuguese coast.

Chapter 3: Final remarks

The five major types of marine litter in the Portuguese coast, according to the ten years of Coastwatch assessment used in this study (2001-2010), were plastic, fishing gears, plastic bags, glass, and paper and cardboard. The scientific literature about marine litter leaves no doubt about the fact that plastic composes the majority of debris in the marine environment worldwide (Derraik, 2002). Due to its versatility, plastic entered every aspect of everyday life (Hansen, 1990). Most plastics degrade at a very slow rate, and when they do, they break into smaller particles, remaining in the natural environment for years, even decades (Hansen, 1990; Pruter, 1987). Also, most of the plastic debris floats, spreading throughout the ocean surface and accumulating in beaches (Pruter, 1987). Fishing gear, also made from plastic and similar non-degradable materials, can persist in the marine environment for long periods of time and, theoretically, continue to capture organisms throughout that time. Despite being classified as different classes of litter in this study, both fishing gears and plastic bags are considered part of the plastic category in most studies (Abu-Hilal and Al-Najjar, 2004; Gago *et al.*, 2014). Despite being the less abundant category of the five major ones, paper and cardboard have a very important component that must be addressed separately, which is cigarette butts. They can be difficult to control, easily dispersed and can sometimes pass through cleaning tools (Oigman-Pszczol and Creed, 2007). Many studies have found cigarette butts as one of the major categories of litter found in beaches, and one that can be easily correlated to beach goers, since many people do not consider leaving cigarette butts on the beach as littering (Moore *et al.*, 2001; Oigman-Pszczol and Creed, 2007; Santos *et al.*, 2005).

Marine litter is a global problem, and as such, there is a need for large scale assessment, in order to have a broader perspective of the problem. A large scale assessment can provide information on amounts, trends and sources of marine litter, and this data can then be used in order to find and implement mitigation measures and to assess the viability of local and international legislation (OSPAR Commission, 2010; Ribic *et al.*, 1992). However, long term assessment poses a difficulty, which is the heterogeneity of methods used throughout the various programs, making it difficult to compare data among different studies (Ryan *et al.*, 2009). Some studies follow the methodologies found in the scientific literature, while others used the ones they used in previous studies, making a comparison between different studies nearly impossible (Velander and Mocogni, 1999).

That is why citizen science programs, like the Coastwatch Program, are so important. This program follows a standard methodology, and samples data through the entirety of the Portuguese coast. However, there are some problems regarding the methodology used to collect the data. The data sheets, or questionnaires, used by the volunteers to record the data collected in the field, suffered major changes through the years. Different methods of recording the abundance of litter, and different classes to categorize the litter were the main alterations to this questionnaires. This changes can undermine the use of the Coastwatch data as a long-term monitoring assessment program, since for this study, the data had to be converted, in order to compare the different years, and in order to assess any possible temporal trends. Changing the classes of litter used to record the data through the years was also a problem for the long-term comparisons of the data. The lack of quality control is another problem. A significant amount of data had to be excluded from the analysis, because it was incomplete or the form was incorrectly filled. As long as this problems are taken into consideration in the near future, it is possible to guarantee long term data for assessment using the Coastwatch Program. The most correct method of sampling the abundance of marine debris should be determined and the questionnaire should be kept unaltered in terms of major components. The abundance classes' methodology should be abandoned, and instead the data should be once again recorded in abundance. Together with the implementation of a quality control protocol in the Coastwatch Project, the data produced would have a much higher quality, and in turn could produce better results.

Assessment methods like the Coastwatch program can also be used as a tool for monitoring the effectiveness of international and national measures. By continuing a constant and homogenous long term assessment in the same areas, it will be possible to assess trends in marine litter quantity and distribution, as well as the effectiveness of different measures in reducing the impacts marine litter has in the coastal habitats. An example is the study made by Alkalay et al. (2007), where an index was developed in order to assess the effectiveness of a long term program that aimed to keep the beaches clean.

Future studies are still needed to address the various long term monitoring programs. This study focused on the Coastwatch program, and pointed out most of its strengths, but also its weaknesses. Despite being a great tool in the environmental education of young citizens in Portugal, it has the major weakness pointed out by investigators in long term monitoring of marine litter: heterogeneous methodology (Velander and Mocogni, 1999).

The changes made in the questionnaires undermines the potential this data had for long term monitoring. However, it was still possible to analyse and extract results from the data. Future studies should focus on the efficiency of the possible measures taken to improve the Coastwatch Project, and on specific impacts marine litter has on the natural environment.

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